UTILIZING STANDING ULTRASONIC WAVES TO HARVEST MICROALGAE FROM A FLUID SUSPENSION

A Senior Scholars Thesis

by

KOLIN J. LOVELESS

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2010

Major: Mechanical Engineering

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Associate Dean for Undergraduate Research: Robert C. Webb

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ABSTRACT

Utilizing Standing Ultrasonic Waves to Harvest Microalgae from a Fluid Suspension.
(April 2010)

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As a result of dwindling supplies of fossil fuels and increasing environmental concerns significant research is being conducted in the United States and throughout the world in search of a new, abundant source of transportation fuel. One such source is biodiesel derived from microalgae; however, separating microalgal particles from the fluid medium where they are cultivated on an economically feasible scale presents a substantial challenge. Methods like sedimentation and flocculation are highly time-consuming, and centrifugation requires significant energy input and frequent repairs. Here, the ultrasonic cell separation techniques employed by Jeremy J. Hawkes and others are applied to the specific case of separating microalgae from a fluid medium. Further, the design and fabrication of a filtration apparatus using this technology is documented along with a recommended test procedure.

DEDICATION

This work is dedicated to all the teachers and friends who have challenged me to pursue the next level of excellence throughout my life. It is my unending desire to have the same impact on the next generation. Mr. Henry Musoma, Mr. Roger Trennepohl, Mr. Brett Peikert, and Mr. & Mrs. Claudio Chisholm, I cannot thank each of you enough for everything that you've taught me throughout the years.

Also to my parents: You've passed on the importance of character, integrity, work ethic, and most importantly, compassion. There's no class, no degree, no experience more important to than the example you have always been, and continue to be for me.

ACKNOWLEDGMENTS

First and foremost, I must thank Dr. Ronald Lacey for his continued support of this project. There have been many delays and constant setbacks, but his steady hand has allowed this work to continue to move forward. Without his help, this idea would still be the Solid Works drawing and a pipe that I started with in the Spring of 2007. Thanks also to my good friend, Nathan Ball, who first told me about Dr. Lacey's work with microalgae. The Aggie Network is a remarkable thing.

Also, I would like to thank General Atomics and the US Air Force for their financial support and guidance of the overall project. Without their commitment to this concept and the future of energy, none of this work would have any meaning nor would it have progressed beyond a piece of scratch paper.

I would be remiss not to also thank the Office of Undergraduate Research at Texas A&M University. Their ongoing work to get more undergraduate students involved in research not only adds substantial value to many students' degrees, but also moves us to the forefront of the premier public institutions in the country.

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CHAPTER I

INTRODUCTION

The United States has imported almost 290 million barrels of crude oil a month from January 2008 to October 2009 according to the Energy Information Agency (Energy Information Agency, 2009). This is even more alarming in light of recent spikes in the cost of oil and a flickering global economy. These events have shown that the US cannot continue to heavily depend on foreign markets to provide the resources necessary to fuel its tremendous energy consumption. The continuing increase of imported energy resources and the hostile relations between the US and oil and gas rich countries like Venezuela, Russia, and Iran has created a movement to seek new, renewable or sustainable sources of energy. One such potential source that has been the recipient of notable media and political attention is biofuels, or chemical fuel in the form of ethanol, diesel, gasoline, or similar species derived from biological sources.

A substantial part of American energy use is petroleum products used in internal combustion engines for transportation, but in recent years, ethanol has been used to supplement the ever-increasing US gas bill. This ethanol can be produced from a large variety of sources including corn, sugar cane, switch grass, and any other form of

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This thesis follows the style of *Applied Engineering in Agriculture.*

biomass. In the United States, most ethanol is produced from corn, which raises great economic concern because of the dramatic increase in feed prices and an increasingly stretched water supply. In response to these challenges, other sources of the biomass that can be used to produce fuels are being researched. One such source is algae, or in some cases, microalgae (Chisti, 2007). Studies indicate that enough algae to replace all transportation fuels in the US can be cultivated using only 4.5 million acres of land (National Renewabl Energy Laboratory, 2002), which is a little less than the size of New Jersey.

No matter what resource is proposed as a new source of energy, its viability will be judged based on its sustainability. Sustainability has three major components that are all interwoven—environment, society, and economics. In the broadest sense, algae already meets the environmental standard in that is it Carbon Neutral, or consumes the same amount of Carbon atoms as it releases during combustion. In terms of society, once algae are converted into any liquid fuel, it can be transported and purchased using existing infrastructure. So, algae appear to be a strong candidate as a sustainable resource based on the first two components (Chisti, 2008). However, the largest unknown with this source of energy is the cost, and the industrial dewatering of microalgae remains a major obstruction to its use in biofuels production (Uduman *et al.*, 2010).

The use of microalgae to produce biofuels requires several complicated processes to filter, or separate, the microalgal particles from the host fluid (Uduman *et al.*, 2010). Here, the standing ultrasonic wave method used by Hawkes, Bosma, Doblhoff-Dier, and others will be evaluated and compared to sedimentation, flocculation, and centrifugation. The energy input and the yield will then be compared to other existing techniques like sedimentation, flocculation, and centrifugation.

Literature review

There are several methods for separating, or harvesting, microalgae from the fluid suspension that receive significant attention from alternative energy advocates. Most of the existing knowledge base for these processes comes from water and wastewater treatment technologies. Below is a summary of these techniques along with an explanation of many of the problems with each and a justification for exploring the standing wave separation process.

Sedimentation

Sedimentation, or settling, can be described as a process by which all the suspended particles settle to the bottom of a vessel as a result of an intertial field—in this case, gravity is considered to be the inertial forces. In its application to water treatment, gravity sedimentation is further defined as “a process that reduces the velocity of water in basins so suspended material can settle out by gravity” (Spellman, 2009). Hence, this process can be delayed when any mechanical perturbation exists in the suspension or accelerated when all such perturbation is removed. According to Spellman, sedimentation is the one of the most basic and most common methods for water or wastewater treatment (Spellman, 2009). However, sedimentation technology is also used widely in bioseparations and other fields such as the clarification of broths and lysates, the collection of cells and inclusion bodies, and the separation of fluids having different densities (Harrison, 2003). As such, much is already known about this technology, even as the problem of separating microalgae is concerned. Uduman found that sedimentation is capable of yielding between 0.5% and 1.5% TSS, but because of its elongated time frame it is a somewhat inefficient method (2010).

Flocculation

While flocculation is often used as a supplement to another separation method, its effect on suspended particles is best articulated separately. In flocculation, a flocculating agent is introduced into the suspension which causes the suspended particles to come together into larger clumps of particles—called flocs—by either forming intermolecular connections that draw particles together or by reducing repulsive forces between cells that keep them separate. More specifically, flocculation occurs when the van der Waals forces between particles are not opposed by electrostatic repulsion, which can also be called colloid instability. Therefore, flocculation is the result of electrokinematic interactions at either the particle or the molecular level (Harrison, 2003). In many water treatment applications, gentle stirring of the suspension can cause particles to collide and the break through the Electric Double Layer where attractive potential energy becomes greater than repulsive potential (Harrison, 2003; Logsdon, 2008). When a flocculating agent is used, each species of algae requires a specific chemical in order for the agglomeration process to begin. As such, the cost of flocculation can vary starting at zero cost, in the case of autoflocculation, where the algae form flocs without any additives. The addition of chemical additives in order to flocculate a medium adds the concern that the microalgae are damaged in the process; however, this is not the case for the majority of cases (Uduman *et al.*, 2010).

Once flocs are formed, it is much easier to extract the larger particles from the suspension using one form of separation or another. Not surprisingly, flocculation is often used with sedimentation or centrifugation to improve the overall filterability of the particles from the suspension and could easily be used to improve standing wave filtration in a similar fashion. However, the chief deterrent for large scale flocculation is the cost of the flocculating agent, or flocculant. For example, the cost of flocculating 8,000 gallons of water to achieve an increase from 0.1% to 10% total suspended solids (TSS) has been found to be around $50 (Lacey, 2010).

Centrifugation

In many ways, centrifugation is simply sedimentation where the inertial force is the centrifugal force in order to separate materials based on their size, shape, density, or mass. The centrifuge spins at a very high speed, and the centrifugal forces that act on the suspension move the particles, which are denser than water, to the outside of the centrifuge while the water moves to the inside. The water can then be removed using a discharge point at the inside of the centrifuge, and the cake that builds up on the outside of the centrifuge are removed by an internal scroll that scrapes particles to another discharge point by spinning slightly faster or slower than the centrifuge (Spellman, 2009). This process is commonly used not only in water treatment, but also in large scale beer production, the separation of plasma from human blood, and a wide variety of other bioseparations. Due to its widespread use in both experimentation and industry, centrifugation is a well understood technology, and studies on its application to microalgae have yielded useful information for this query. In 2010, Lacey found that 8,000 gallons of algae filled water could be dried from 0.1% to 10% TSS using 169 kwh of power (unpublished data). At a rate of $0.08/kwh, the total cost can be found to be $13.52, which is substantially lower than the cost found for flocculating a similar volume of suspended algae. Furthermore, this process becomes the benchmark against which standing wave filtration is to be compared.

Standing wave filtration

A standing wave is a wave where the peaks and nodes remain in a constant location as one would observe by carefully studying the string of a musical instrument as it resonates. In the case of standing waves in a fluid flow, the flow must pass through a trough with walls perpendicular to the centerline of the wave so that the wave is reflected back onto itself and the trough width must be set as one half of the wavelength of the standing wave.

Standing wave filtration uses a standing wave to force the less dense particles of the suspension to the node of the wave and creates a high concentration of suspended materials over time as shown in Figure 1.

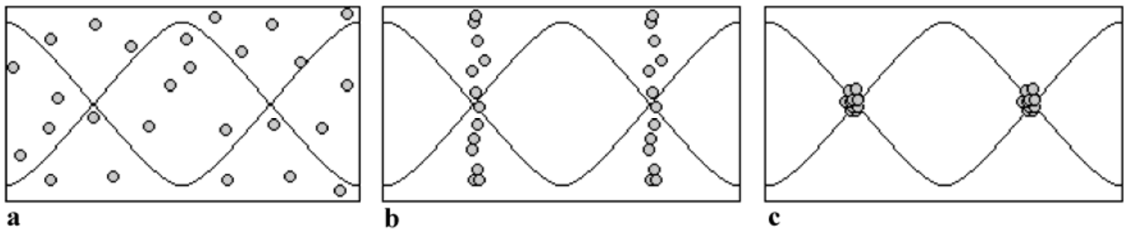

Figure 1. Agglomeration of particles at the nodes of a standing wave (Bosma, 2003).

The figure shows the agglomeration of particles at the nodes of the standing wave, a phenomenon which is employed to draw suspended particles to the center of flow to achieve a higher algae concentration. The effect of this concentration is similar to flocculation in that sedimentation and filtration become more effective as the cell agglomeration grows (Hill and Harris, 2008). However, another method that can be used to increase TSS concentrations is to simply separate the region of the flow where the higher concentration of effluent exists from the clarified regions of the solution. This can be accomplished by positioning the node of a half-length standing wave in the center of the flow and directing the sides of the flow into a separate container from the center of the flow where the microalgae particles have agglomerated as shown in Figure 2. (Hawkes, 2001; 2004; 1996; 2002; Hill, 2004; 2008; Bosma, 2003).

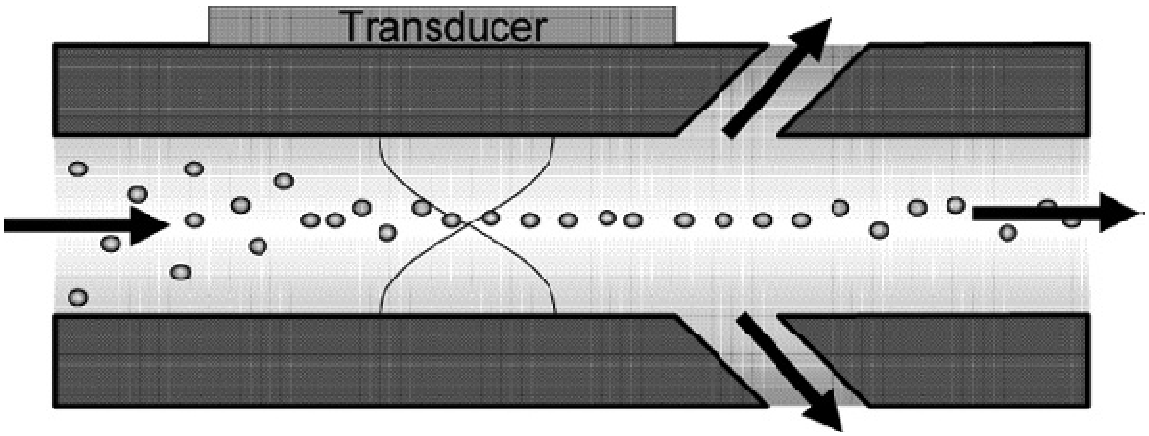

Figure 2. Clarified water is separated from the slurry after microalgae particles are forced to the center of the flow by a standing wave generated by the transducer (Hill and Harris, 2008).

Much of the work that has been done using standing waves to separate a desired crop from a liquid suspension has tested solutions of yeast or bacteria. However, very little has been done in this area in specific regard to microalgae. Hence, its potential, especially for biodiesel production, should be studied further.

Objectives

With an understanding of the functionality of typical separation processes in mind, the primary endeavor of this work is to gain a more detailed knowledge of standing wave filtration and its behavior for applications in separating suspended microalgae. In order to accomplish this, a standing wave filtration system must be designed, fabricated, and tested. However, due to time constraints, this work will document the design and fabrication of a test filtration block as well as establish a test protocol.

CHAPTER II

METHODS

While Hawkes, Bosma, Doblhoff-Dier, and company establish that standing wave filtration is a feasible method for particle and fluid separation, there is much left to be determined for its application to microalgae separation (Hawkes, 2002; Doblhoff-Dier, 1994; Bosma, 2003). First, any excessive shear of the particles could result in tainted biomass that is useless in terms of producing fuel. This concern is shared for centrifugal separation technology; however, it has been shown that the problem can be avoided (Lacey, 2010, unpublished data). It is expected that standing wave filtration will place a lower shear than that of centrifugation on the particles, but this certainly requires empirical data to ensure that the end results is useful biomass. Second, the operating cost of microalgae separation in relation to sedimentation, flocculation, and centrifugation is unknown. The energy input required for both centrifugation and standing wave filtration is substantial, and the time required for sedimentation and flocculation can reduce the biomass yield. Data may be found for the relative performance sedimentation, flocculation, and centrifugation; however, similar data for standing wave filtration remains unknown. Hence, the scope of this work is to find relevant data for standing wave filtration including: cost input over time, percentage moisture content (the inverse of percent biomass) in the output, and the overall cost needed to achieve between 80% and 90% moisture content, or 10-20% TSS, in the output. In order to find these data, cost input will be the independent variable of testing, and the moisture content in the output and the cost to achieve between 80% and 90% moisture content will be dependent variables. The operating cost of the system can be determined by adding the cost of the cost of energy to run the piezoelectric and the cost of operating a pump to maintain the flow rate. The costs for materials for the standing wave separator are fixed capital costs. Therefore, independent variables to be tested are the energy input into the piezoelectric element and the energy input to maintain the flow rate.

Design

Design of the filtration block

Conceptual design

Using the knowledge gained from Hawkes, Gröschl, and Bosma, a prototype filtration block was designed and fabricated for testing (Bosma, 2003; Doblhoff-Dier, 1994; Hawkes, 2001; 2004; 2002; 1996; Hill, 2004). Understanding the standing wave concept is central to the design of a standing wave filtration system. A standing wave is a wave where the peaks and nodes remain in a constant location as one would observe by carefully studying the string of a musical instrument as it resonates. In the case of standing waves in a fluid flow, the flow must pass through a trough with walls perpendicular to the centerline of the wave so that the wave is reflected back onto itself. The width of the trough and the material used to form the trough must be properly sized so that the node of the wave falls exactly in the center of the flow, or so that the width of each is equal to n times the half wavelength. Also, the flow must pass through a trough with walls perpendicular to the centerline of the wave so that the wave is reflected back onto itself. The wavelength through a given medium was found using the equation

$$\lambda = \frac{v_m}{f} \tag{1}$$

where v_m is the speed of sound through the medium and f is the design frequency, which was chosen to be 100 kHz. Similarly, the width of the material and the trough can be found by

$$w_m = n\frac{\lambda}{2} = n\frac{v_m}{2f} \tag{2}$$

where n is the number of wavelengths that are designed to occur in the material, w_m is the design width of either the trough or the block material. Using this information, a filtration block was designed where the unfiltered suspension would enter, pass through a standing wave field where the microalgae particles move toward the node of the wave as shown in Figure 1. Because this node occurs at the center of the trough, the concentrated particles exit the block in the middle of three troughs while the remaining water passes through two side troughs as shown in Figure 2. The force responsible for this phenomenon is the acoustic force generated from the standing wave, which is given by the equation

$$F_{ac} = -\left(\frac{P_0^2 V_p \beta_f \pi}{2\lambda}\right)\left(\frac{(5\rho_p - 2\rho_f)}{(2\rho_p + \rho_f)} - \frac{\beta_p}{\beta_f}\right)\sin\left(\frac{4\pi z}{\lambda}\right) \tag{3}$$

where P_0 is the peak sound pressure, ρ_p and ρ_f are the particle and fluid densities respectively, β_p and β_f are the compressibilities of the particles and fluid, λ is the wavelength of sound in the suspending phase, V_p is the particle volume, and z is the distance normal to the pressure node (Hawkes, 2004). The majority of Hawkes' work shows the use of two troughs—one for concentrated particles and one for clarified fluid; however, an improved concentration effect is expected using two troughs for clarified fluid (Hawkes, 2001). (See Figures 3 and 4).

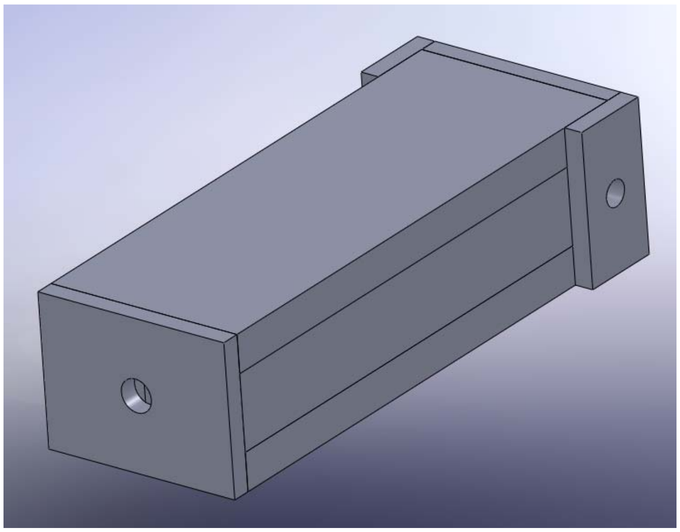

Figure 3. Outside view of filtration block design.

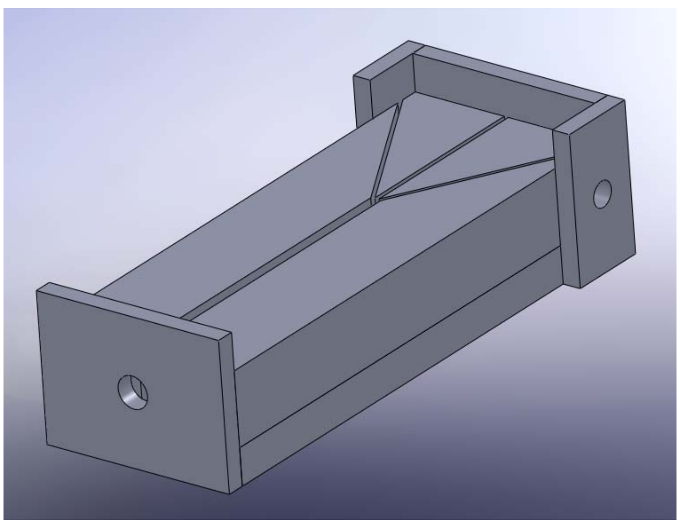

Figure 4. Inside view of filtration block design.

Design details and fabrication

The material for the filtration block was selected to be aluminum with a width of 2.53 inches on each side of a trough that is 0.3 inches wide at the inlet and separates into three outlet troughs. The center trough, where the concentrated microalgae particles will exit the filtration block, will be 0.12 inches wide while the two side troughs that will contain a higher water concentration will be 0.1 inches wide as can be seen in Figure 5, Figure 6, and Figure 7. The design allows for one full wave to pass through the Aluminum side of the filtration block and one half wave in the trough. Because of the large difference in the speed of sound through Aluminum and water (6420 and 1497 meters per second, respectively), a negligibly small fraction of the energy from the wave generator will transfer through the trough and into the Aluminum on the other side. Conversely, a large fraction of the energy from the piezoelectric will be trapped in the trough in the form of a standing wave. Due to round off errors and manufacturing tolerances, the frequency of the piezoelectric element will have to be tuned to the system with a reasonable approximation of the design frequency, 100 kHz.

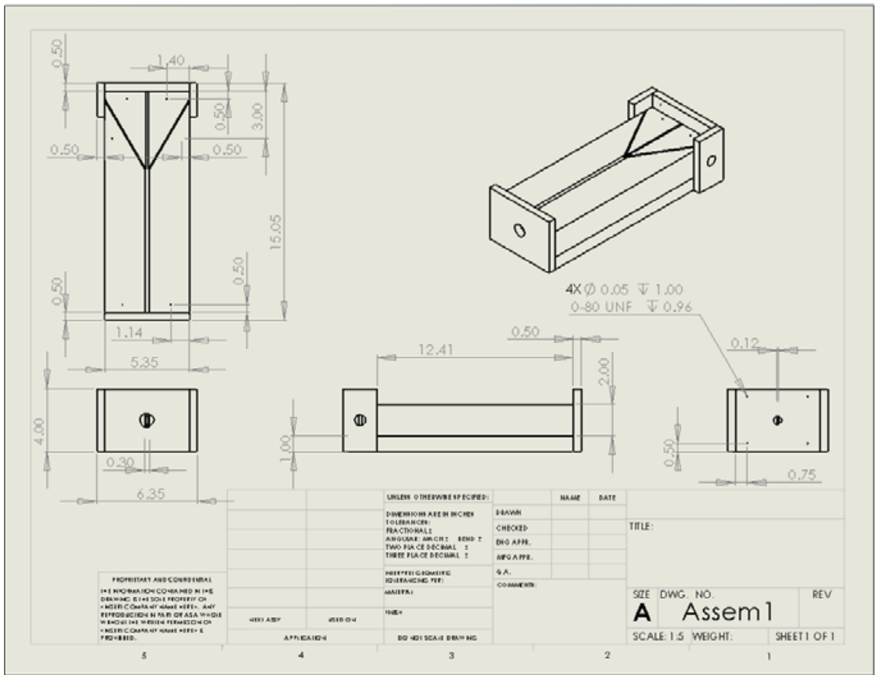

Figure 5. Technical drawing of the filtration block generated using Solidworks that shows key assembly dimensions.

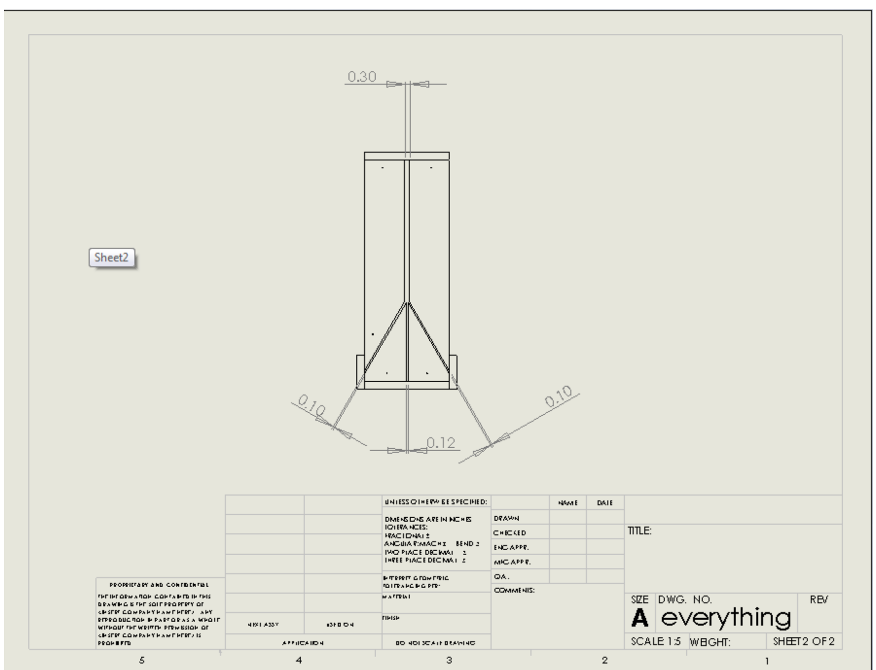

Figure 6. Technical drawing of the filtration block generated using Solidworks that shows the trough dimensions.

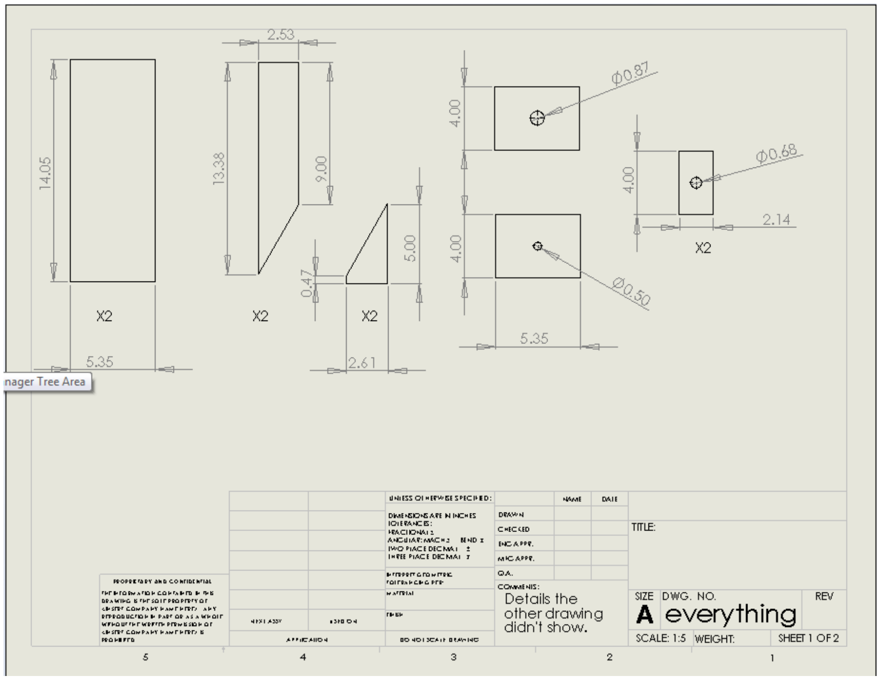

Figure 7. Technical drawing of the filtration block generated using Solidworks that shows key component dimensions.

For ease of manufacturing, the filtration block was machined as 9 separate parts that are fastened to each other using screws. Each screw should be fastened tightly so that no fluid leakage occurs in the filtration block.

Testing

Recommended testing methodology

Assembly

The test apparatus is assembled as described in the design of the filtration block above to match existing conditions and equipment at Texas A&M University:

1. Assemble the filtration block by placing the each part in place as shown below and inserting screws into each hole in order to hold the set up in place.
2. Attach the tubing to the one input and to the three output channels.
3. Calibrate two optical density sensors by measuring a sample with the sensor and then determining the Ash-Free Dry Weight of the sample. The process must be repeated for each test.
4. Attach optical density sensors to the unfiltered input and the filtered center output tubing.
5. Attach the piezoelectric plate with a known electrical resistance to one side of the filtration block with leads connected to a power source and set the data acquisition system (DAQ) to record the electrical frequency and power input into the plate.
6. A pump and the change in height from the tank to the filtration block will be used to control the flow rate as the suspension enters the filtration block. Also, connect the power source to the pump into the DAQ system so that its power consumption can be monitored along with the piezoelectric plate. A diagram of the full test apparatus can be found in Figure 8.

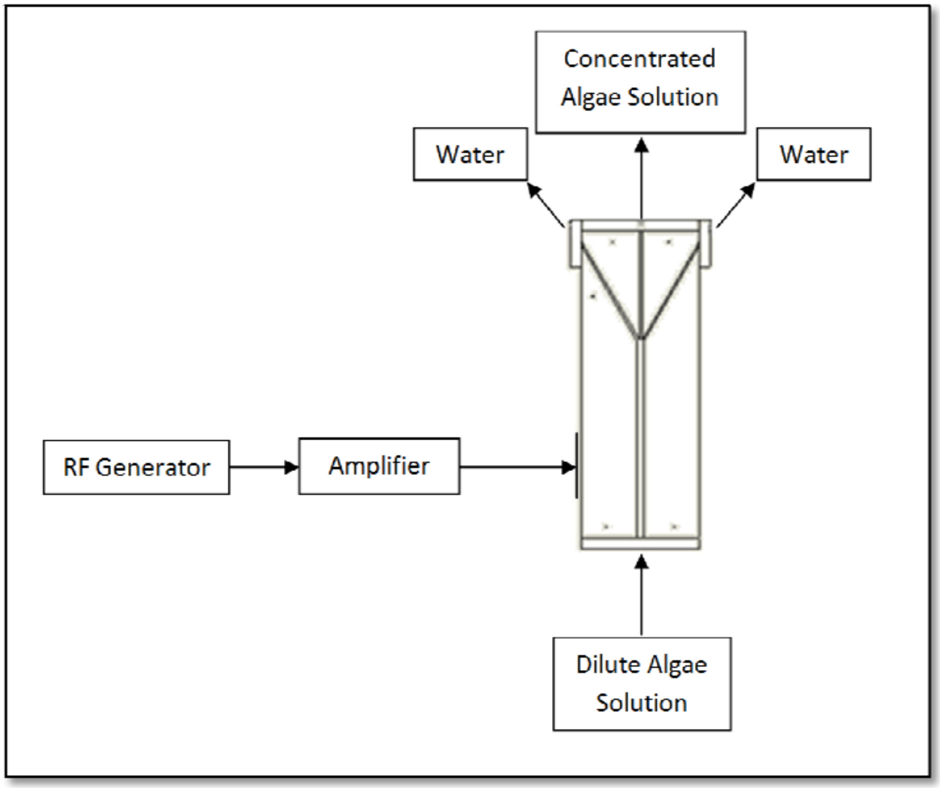

Figure 8. Filtration system diagram.

Proof test

The initial test will be a proof of concept test establishing that standing wave filtration increases the biomass content in the output without shearing the particles. Particles will be filtered and then analyzed for their health and ability to be converted into hydrocarbons:

1. Remove one gallon of suspended biomass in water and place it in a separate tank for filtration testing
2. Using an optical density sensor measure and record the biomass content of the suspension in Table 1 before any filtration has been executed.

3. Turn on the DAQ and begin running a current through the piezoelectric.
4. Turn on the pump so that flow begins to move through the filtration block.
5. Before the one gallon tank is completely emptied, turn off the pump and the DAQ system.
6. Using an optical density sensor measure and record the biomass content in the filtered suspension in Table 1.
7. Inspect the microalgae to determine if the particles have been damaged by comparing the growth rate of a filtered sample to one that has not been through the standing wave separation process. Record the results in Table 1.
8. After the proof testing has been completed, note the total energy used by the piezoelectric plate and the pump along with the gain in biomass content of the filtered suspension.

Table 1. Proof Test Record

	Current	Flow Rate	Biomass Content	Microalgae Condition	Plate Power Comsumption	Pump Power Consumption
Test 1						
Test 2						
Test 3						
Test 4						
Test 5						
Test 6						
Test 7						
Test 8						
Test 9						

Batch filtration test

The initial test will be a proof of concept test establishing that standing wave filtration increases the biomass content in the output without shearing the particles. It will measure the increase in the ratio of microalgae to water after each batch and document the difference between three different power inputs:

1. Remove one gallon of suspended biomass in water and place it in a separate tank for filtration testing
2. Using an optical density sensor measure and record the biomass content of the suspension in Table 2 before any filtration has been executed.
3. Turn on the DAQ and begin running a current through the piezoelectric as specified in Table 2.
4. Turn on the pump so that flow begins to move through the filtration block at the flow rate specified in Table 2.
5. Before the one gallon tank is completely emptied, turn off the pump and the DAQ system.
6. Using an optical density sensor measure and record the biomass content in the filtered suspension in Table 2.
7. Inspect the microalgae to determine if the particles have been damaged by comparing the growth rate of a filtered sample to one that has not been through the standing wave separation process. Record the results in Table 2.
8. Repeat steps 3 through 7 until the desired moisture content has been achieved.

9. After the proof testing has been completed, note the total energy used by the piezoelectric plate and the pump along with the gain in biomass content of the filtered suspension.
10. Repeat steps 1 through 9 for the different power inputs and flow rates specified in Table 2.

Table 2. Batch Filtration Test Record

	Current	Flow Rate	Biomass Content	Microalgae Condition	Plate Power Comsumption	Pump Power Consumption
Test 1						
Test 2						
Test 3						
Test 4						
Test 5						
Test 6						
Test 7						
Test 8						
Test 9						

Continuous filtration test

1. Remove one gallon of suspended biomass in water and place it in a separate tank for filtration testing.
2. Using an optical density sensor, measure and record the biomass content of the suspension in Table 3 before any filtration has been executed.
3. Connect the center output from the filtration block back to the one gallon filtration testing tank.

4. Turn on the DAQ and begin running a current through the piezoelectric as specified in Table 3.
5. Turn on the pump so that flow begins to move through the filtration block as specified in Table 3.
6. Continue running the system until the desired moisture content (80% - 90%) has been achieved.
7. Using an optical density sensor measure and record the biomass content in the filtered suspension in Table 3.
8. Inspect the microalgae to determine if the particles have been damaged by comparing the growth rate of a filtered sample to one that has not been through the standing wave separation process. Record the results in Table 3.
9. After the proof testing has been completed, note the total energy used by the piezoelectric plate and the pump along with the gain in biomass content of the filtered suspension.
10. Repeat steps 1 through 9 for three different power inputs and then three different flow rates as specified Table 3.

Table 3. Continuous Filtration Test Record

	Current	Flow Rate	Biomass Content	Microalgae Condition	Plate Power Comsumption	Pump Power Consumption
Test 1						
Test 2						
Test 3						
Test 4						
Test 5						
Test 6						
Test 7						
Test 8						
Test 9						

Statistical analysis

Once the data for these tests have been collected, analysis of variance by ANOVA can be used to evaluate main effects and interactions.

CHAPTER III

SUMMARY AND CONCLUSIONS

As political and public interest for alternative and renewable energy resources, Algae has become a strong candidate to replace transportation fuel needs. However, there are still a large number of hurdles for this technology to overcome before it will be ready to meet a growing energy demand. The critical element of any new energy technology will be its cost, and the standing wave filtration technique explored here has a large number of questions that are yet to be answered. Also, there are several other possibilities that this technology introduces to microalgae filtration beyond single standing wave filtration.

Concerns

As was mentioned throughout this document, the cost of standing wave filtration remains a major concern. The capital and maintenance costs of standing wave filtration are expected to be very low. All of the major system components can be purchased at a low cost, and the only moving parts are the pump and the piezoelectric plate. However, the operational costs might be substantial. Both the pump and the piezoelectric plate will be constantly consuming energy during filtration, significantly increasing the cost of operation as the system operates. Another major concern that this presents is the energy balance of this technology. Because the pump and the piezoelectric plate will be operating throughout the filtration process and filtration will only reduce the moisture content to between 80% and 90%, it seems unlikely that the chemical energy of the algae in the output will be greater than the sum of the energy inputs.

Possibilities

Standing wave filtration also offers many possibilities for improved separation modifying the nodal pattern in the wave field or by combining existing technologies. One such modification to standing wave filtration technology for which extremely limited information is know is the use of multiple nodes in the standing wave region. This would require some modification to the filtration block; however, this can be done at a small capital cost by designing and machining the block to new specifications. Another additional cost to this modification is the additional energy that will be consumed moving a larger volume of water both by the pump and by the piezoelectric plate. In spite of these additional costs, this method could potentially yield a larger filtration per cost ratio. Once more information is know about standing wave filtration from the test outlined above, further analysis on this modification should be explored. Another variable that remains unstudied is the length of the standing wave region in the trough. It is crucial that this length be optimized so that maximum particle agglomeration is achieve while eliminating unnecessary standing wave length that adds to energy consumption without increasing the TSS mass.

Also, standing wave filtration adds several potential combinations of separation technologies that should be further explored. As previously explained, flocculation is the addition of a chemical agent that draws particles in a suspension together. When this separation method is combined with standing wave filtration, it seems likely that a larger amount of separation will occur. However, this method will need to be tested to confirm that the effects of flocculation are not reversed by the standing wave field. Another concern with this method is, as always, the separation to cost ratio. Similarly, standing wave filtration or the combination of flocculation and standing wave filtration can be combined sedimentation by passing the suspension through a standing wave field and then allowing the concentrated microalgae to settle to the bottom of a tank. As each of these methods is combined with another, it retains the concerns of both of the methods. Hence, the amount of time to settle out, the cost of the flocculant, and the energy cost of operating a pump and a piezoelectric plate are all concerns for a method combining sedimentation, flocculation, and standing wave filtration. Ultimately, the highest separation to cost ratio is the method that should be used to separate microalgae from a fluid suspension.

Conclusions

In closing, the principle information that this testing should find is a confirmation that this method does not harm the microalgae, the increase in algae concentration, the amount of electrical power input, and the ratio of the increase in algae concentration to the cost of the power input. Using this data, this method can then be compared to other forms of filtration that are used to separate microalgae from a fluid suspension.

As it stands, microalgae has strong potential as chemical feedstock for conversion into biodiesel, and standing wave filtration may be the best way to separate microalgae from the suspension in which it is grown. However, the cost of separation is the determining factor in choosing which method should be used. Once the testing outline above has been completed, it will be possible to rate this separation technique against other techniques for which more information is known.

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